# Terrestrial small mammals of the Abydos Plain in the north-eastern Pilbara, Western Australia

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## Abstract

Repeated surveys over three years of the 1500 km² Abydos/Woodstock Reserve, in the Pilbara of Western Australia, recorded 14 species of small terrestrial mammals including four endemic to the broader Pilbara area. Five species were captured frequently throughout the study. Captures of the dasyurids *Dasykaluta rosamondae* and *Ningaui timealeyi* increased when juveniles entered the population following seasonal breeding. Captures of the saxicoline rodent, *Zyzomys argurus*, showed relatively small fluctuations whereas populations of two other rodents, *Pseudomys hermannsburgensis* and *Mus musculus*, had 40 to 50 fold increase in captures between troughs and peaks, with peaks for both species occurring 18 months after the first of two major rainfall events. Species showed marked differences in their response to capture in Elliott and pitfall trap types; consequently, assemblage composition was compared in only eight habitats where both types were employed. The small mammal assemblage adjacent to a rocky breakaway differed to that on alluvial soil adjacent to the major creek, and to those in several *Triodia*-dominated habitats on the Abydos sandplain. The number of small mammal species and individuals in *Triodia*-dominated habitats decreased markedly after fire while similar habitats that remained unburnt over the same period showed an increase in both species and capture rates of individuals.

Keywords: dasyurid, rodent, trapping, capture rate, annual variation, habitat preference, fire response

## Introduction

Several recent studies have evaluated or collated information on the demographic response of small mammal species to temporal changes in environmental variables across much of the extensive arid and semi arid landscapes of Australia (Masters 1993; Predavec 1994; Dickman *et al.* 1995, 1999, 2001; Carthew & Keynes 2000). There have also been important attempts to evaluate and explain changes in mammalian populations in response to environmental modifications imposed by European settlement (Morton 1990; Stafford-Smith & Morton 1990). Temporal and regional variations of murid rodent populations examined for over a decade have been synthesized by Dickman *et al.* (1999), who showed that the majority of species had a strong positive correlation between numbers and preceding rainfall. The nature of this correlation varied temporally for different species. Dasyurid marsupial populations showed less marked temporal changes, and these were generally correlated with changes in environmental variables other than rainfall (Masters 1993; Dickman *et al.* 2000). Arid regions cover 55 percent of Australia (Williams & Calaby 1985) but detailed studies of small mammal species have focused on populations in central and eastern Australia with only How *et al.* (1991) reporting on species in Western Australia.

Despite the large area and extensive development in the Pilbara there have been few attempts to systematically document the faunal diversity of the region on a systematic basis (Dunlop & Sawle 1980; How *et al.* 1991). As part of a three-year survey to document the faunal diversity of the Woodstock and Abydos stations, data were gathered on the composition and structure of numerous vertebrate assemblages in the area (How *et al.* 1991). These data provided baseline information on biodiversity for future management of the area (Berry *et al.* 1991) and were the first examination of seasonal and annual variation of vertebrate populations in one of the least known regions of arid Western Australia.

Agricultural and biological research has elevated Woodstock Station to the forefront of scientific understanding of the Pilbara region. Classical research on the ecology of the euro (Ealey *et al.* 1965; Ealey 1967a,b,c), vegetation (Burbidge 1943, 1945, 1959) and the effects of fire and grazing (Suijendorp 1955, 1967, 1980) provide unique information on arid zone ecology. The native mammal fauna has been documented over the last 50 years through collections lodged in the Western Australian Museum by numerous research scientists and by several studies on species biology (Woolley 1991a,b). Species whose first known records are from Woodstock Station include *Dasykaluta rosamondae* (Ride 1964), *Ningaui timealeyi* (Archer 1975), *Pseudomys chapmani* (Kitchener 1980) and *Pseudantechinus roryi* (Cooper *et al.* 2000); it is the type locality of *D. rosamondae* and *P. roryi*. At the completion of the Western Australian Museum survey in 1990, 31 species of mammals in 13 families had been recorded from the area, including four species (*Dasycercus cristicauda, Lagorchestes conspicillatus, Macrotis* *lagotis, Pseudomys chapmani*) that were listed as threatened taxa at that time (How *et al.* 1991).

In this study we examine the composition and habitat relationships of the small mammal assemblage on the Abydos Plain and document demographic changes for the more-frequently captured species over a three-year period.

## Methods

### Study area

The Abydos and Woodstock Stations cover an area of over 150 000 hectares of the northern Pilbara, 150 km south of Port Hedland. They cover the upper reaches of the Yule and Turner Rivers that drain north-westerly across a major physiographic unit of the Pilbara, the Abydos Plain (Fig 1). In 1882 two leases were granted which were to form the basis of Abydos Station, while a stone homestead was built on Woodstock Station in 1883/84 (Bindon 1979). Discovery of gold at Tambourah induced the Woodstock lessee to use the homestead as an inn until around 1898 when sheep grazing again became the primary land use. Grazing continued until the lease was taken over in 1945 by the Western Australian Department of Agriculture, which conducted research on the impacts of both grazing and fire on the vegetation of the region. In 1978 Abydos/Woodstock was vested in the Western Australian Museum and in February 1991 the vesting of the reserves was transferred to the indigenous people of the Mumbultjari Corporation.

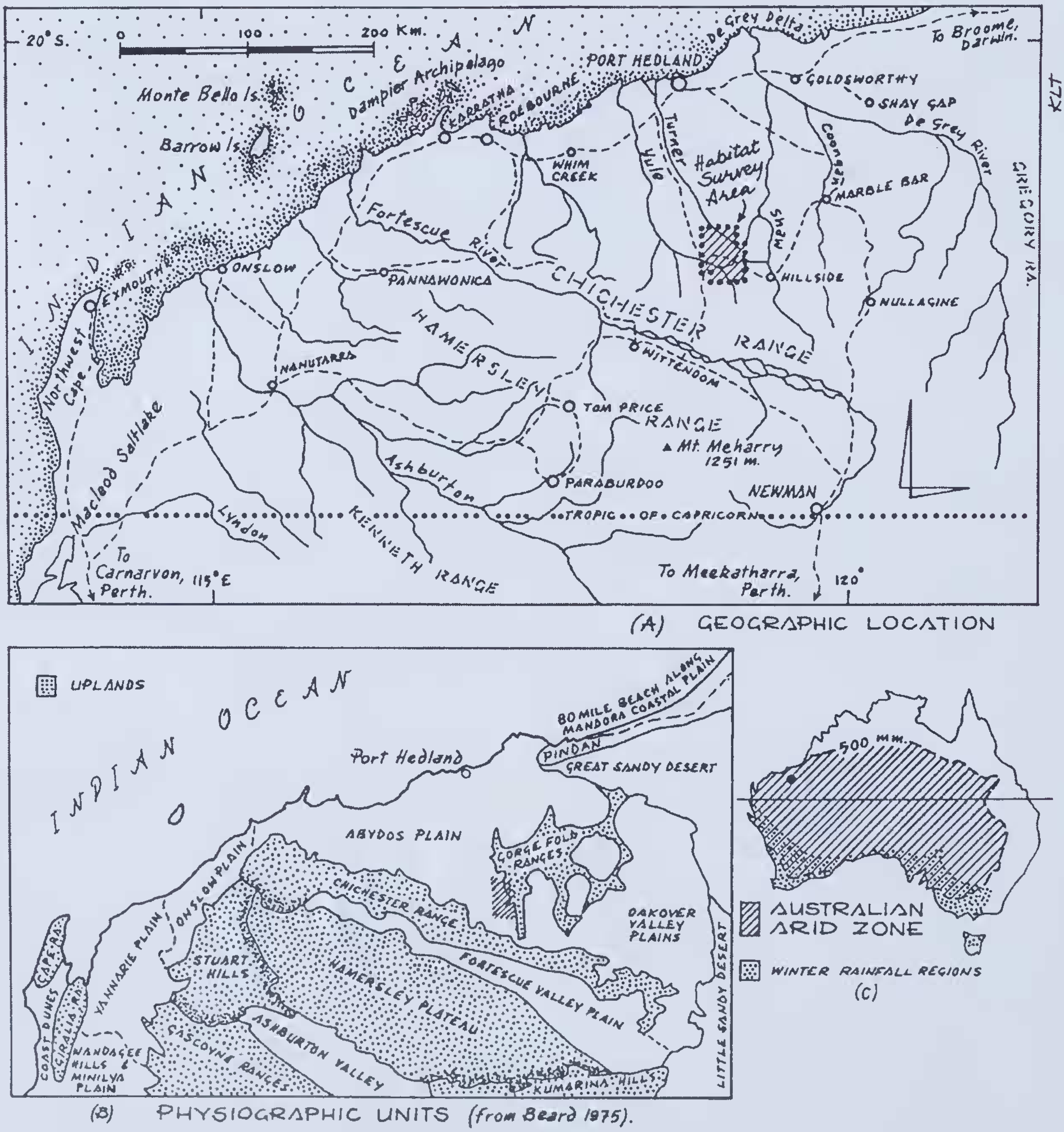


Figure 1. Geographic location of the Woodstock-Abydos Station study area and major physiographic units of the Pilbara region, including the Abydos Plain (after Tinley 1991a).

Table 1

Monthly and total rainfall registered at Woodstock Station for each month between January 1987 and October 1990.

| Years | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | 95.2 | 78.8 | 0 | 0 | 4.8 | 0 | 8.5 | 0 | 0 | 0 | 0 | 23.0 | 210.3 |
| 1988 | 61.9 | 10.0 | 252.2 | 8.0 | 109.2 | 0.8 | 0 | 49.7 | 0 | 0.4 | 1.9 | 72.4 | 566.5 |
| 1989 | 63.4 | 227.0 | 0.4 | 46.2 | 9.0 | 117.9 | 2.3 | 0 | 0 | 0 | 4.0 | 11.2 | 484.4 |
| 1990 | 79.2 | 6.6 | 0 | 0 | 0 | 3.4 | 0 | 0 | 0 | 0 | | | |

The long-term climatic averages for the region are presented by Tinley (1991a). Over the three years of this study, rainfall showed significant seasonal and annual variation (Table 1). Major episodic rainfall events in March 1988 and February 1989 resulted in the flooding of Coorong Creek and all other ephemeral streams and drainage lines in its catchment.

### Sampling sites and climate

The regional landforms and vegetation of the Abydos/Woodstock Reserve were described in detail by Tinley (1991b) and formed the basis for selecting sampling sites for the study of small mammals.

Eight sampling sites were selected to represent the major habitats identified on the sands of the Abydos Plain, while an additional 20 sites were selected to sample the granite tors on the Abydos Plain and adjacent rocky escarpments of the George Fold Ranges. The eight major sampling sites were:

WS1 *Eucalyptus camaldulensis*, *Melaleuca leucadendra* 5-8 m tall, 35% canopy cover, over *Acacia* sp 1-2 m tall, *ca* 5% canopy cover over *Cenchrus ciliaris* <0.5 m tall, *ca* 90% canopy cover. Site is narrow belt of riverine woodland on edge of Coorong Creek. Soil is deep alluvium.

WS2 *Acacia pyrifolia*, 2-3 m tall, 3% canopy cover, *Hakea suberea*, 2-3 m tall, <0.5% canopy cover and *Acacia* sp 2-3 m tall, <0.5% canopy cover over *Triodia* spp (2) *ca* 0.5 m tall, 80% canopy cover. Soil coarse sandy loam with granite bedrock at 30-40 cm and located 200 m from Coorong Creek. Site was burnt in January 1990.

WS3 *Triodia* spp <1 m tall *ca* 60% canopy cover with occasional *Acacia* spp as emergents. Soil red sandy loam in an ephemeral drainage line. Site was burnt in January 1990.

WS4 *Acacia pyrifolia*, 2-4 m tall, *ca* 5% canopy cover, over *Acacia ancistrocarpa*, 1.5-2 m tall, 50%-70% *Triodia* spp canopy cover. Occasional ephemerals after rain. Soil red sandy loam, >60 cm deep. Site was burnt in January 1990.

WS5 *Triodia secunda* and *T. longiceps* <0.5 m tall, *ca* 70% canopy cover. Soil white sandy silt over clay.

WS6 *Acacia orthocarpa*, 3-4 m tall, *ca* 7% canopy cover, and occasional *A. pyrifolia*, over *Triodia lanigera ca* 0.5 m tall, 50% canopy cover. Soil is skeletal red granitic sand.

WS8 *Eucalyptus terminalis*, 3-5 m tall, *ca* 2% canopy cover, over oval leaf wattle 1-1.5 m tall, *ca* 2% canopy cover, over *Triodia ca* 0.5 m tall, *ca* 40% canopy cover. Site includes valley between, and the steep slopes of calcrete mesas. Valley soil is calcareous clay loam.

WS10 *Acacia* sp 1.5-2.5 m tall, <0.5% canopy cover, *Hakea* sp 1.5-2.5 m tall, <0.5% canopy cover, over *Acacia* sp <1m tall, *ca* 3% canopy cover, over *Triodia* sp <0.5 m tall *ca* 60% canopy cover. Deep red loamy sand. Extensive surface water after heavy rain.

Fires were frequently seen around the study area, and small areas on the eastern edge were burnt in January and February 1989. In January 1990 lightning strikes started numerous small fires, three of which burnt out sampling sites WS2, WS3 and WS4 and several hundred hectares of the surrounding areas.

### Sampling methods

The eight lines of fenced pitfall traps each comprised a 50-m long 30-cm high flyscreen mesh fence that crossed six pitfall traps inserted 600 mm into the substrate. Pitfall traps were generally made of 175 mm diameter PVC pipe 600 mm deep, but at several sites where the soil was less than this depth, piping was replaced with 400 mm deep conical pits. At each of the eight sampling sites a line of 15 Elliott Type A traps, baited with universal bait, were set 15 m apart and within 50 m of the fenced pitfall trapline. Fifteen Elliott Type B traps were used on rockpiles along with Type A traps. Traps were checked shortly after dawn and again in the late afternoon each day.

Sampling occurred in summer (February- March) and spring (September- October) in each of the three years, while three additional sampling periods examined activity at other times of the year. The nine surveys were undertaken between 21-31 March 1988, 2-9 May 1988, 22-30 September 1988, 9-17 February 1989, 16-24 April 1989, 16-24 September 1989, 26 February-7 March 1990, 25 July-2 August 1990 and 24 October-1 November 1990.

Regular trapping was undertaken on all surveys except May 1988, when only the fenced pitfall traplines were used, and April 1989 when, principally, Elliott traplines distant from the regular sampling sites were set. Only Elliott traps were set in areas where the substrate was either too rocky for fenced pitfall lines (screeslopes, rockpiles) or subject to seasonal inundation (creek beds).

All individuals captured were identified, measured and weighed to determine body mass. Voucher specimens were taken of all species.

Over all habitats and the nine sampling periods, there were 8131 Elliott trapnights and 2484 pitfall trapnights. Pitfall traplines were open on 58 days of the 74 days over which trapping occurred (Table 2).

### Analyses

Least squares regression and analysis of variance were performed using the Statistix (1996) software package. Comparison of means between classes were made using Least Significant Differences with $\alpha = 0.05$. Assemblage analyses were carried out using the NTSYSpc (2000) program with UPGMA clustering of the Bray-Curtis index.

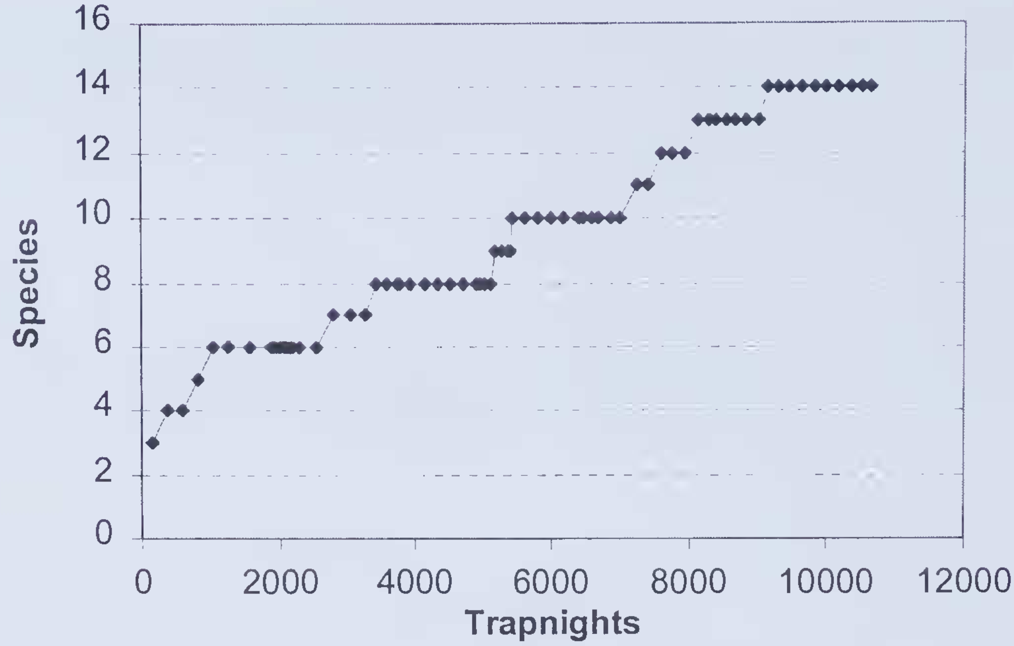


Figure 2. Cumulative number of terrestrial small mammal species captured for all trapnights between March 1988 and October 1990.

## Results

### Species

Fourteen species of small terrestrial mammals recorded on the Abydos Plain and associated landforms included nine dasyurid marsupials (*Dasyurus hallucatus*, *Dasycercus cristicauda*, *Dasykaluta rosamondae*, *Ningaui timealeyi*, *Planigale* sp, *Pseudantechinus roryi*, *Pseudantechinus woolleyae*, *Sminthopsis macroura*, *Sminthopsis youngsoni*) and five murid rodents (*Mus musculus*, *Pseudomys delicatulus*, *Pseudomys chapmani*, *Pseudomys hermannsburgensis*, *Zyzomys argurus*). Four species (*Planigale* sp, *S. macroura*, *S. youngsoni*, *P. delicatulus*) were recorded for the first time on the Abydos Plain. Recording of new species towards the end of the 74 trapping days (Fig 2), indicates that additional species may still be found in the area.

Three groups of species can be recognised on the basis of their response to capture in different trap types; those preferentially caught in Elliott traps (*D. hallucatus*, *S. macroura*, *P. woolleyae*, *P. chapmani*, *Z. argurus*), those preferentially caught in pitfall traps (*D. cristicauda*, *N. timealeyi*, *Planigale* sp, *S. youngsoni*, *P. delicatulus*) and those caught in both types of trap (*D. rosamondae*, *P. roryi*, *P. hermannsburgensis*, *M. musculus*) but more frequently in Elliotts (Fig 3). Four species (*S. macroura*, *S. youngsoni*,

**Table 2**

Number of captures of small mammal species in pitfall and Elliott trap types on the Abydos Plain during nine sampling periods between March 1988 and October 1990. Total number of pitfall/Elliott traps set during each sampling period is also presented.

| | 1988 Mar | 1988 May | 1988 Sep | 1989 Feb | 1989 Apr | 1989 Sep | 1990 Mar | 1990 Jul | 1990 Oct | total |
|---|---|---|---|---|---|---|---|---|---|---|
| *D. cristicauda* | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 1/0 | 0/0 | 0/0 | 1/0 |
| *D. hallucatus* | 0/0 | 0/0 | 0/0 | 0/0 | 0/4 | 0/3 | 0/3 | 0/0 | 0/1 | 0/11 |
| *D. rosamondae* | 2/1 | 0/0 | 4/5 | 0/1 | 0/0 | 5/3 | 1/18 | 1/1 | 0/9 | 13/38 |
| *N. timealeyi* | 4/0 | 5/0 | 4/0 | 4/0 | 0/0 | 12/0 | 3/0 | 1/0 | 3/0 | 36/0 |
| *Planigale* sp | 1/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 1/0 |
| *P. roryi* | 0/0 | 0/0 | 0/0 | 0/0 | 0/1 | 0/0 | 0/0 | 1/5 | 0/3 | 1/9 |
| *P. woolleyae* | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/1 | 0/1 | 0/2 |
| *S. macroura* | 0/0 | 0/0 | 0/1 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/1 |
| *S. youngsoni* | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 1/0 | 0/0 | 0/0 | 1/0 |
| *M. musculus* | 0/3 | 0/0 | 0/15 | 0/6 | 0/2 | 3/75 | 0/8 | 0/2 | 0/4 | 3/115 |
| *P. chapmani* | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/4 | 0/1 | 0/1 | 0/0 | 0/6 |
| *P. delicatulus* | 0/0 | 0/0 | 2/0 | 1/0 | 0/0 | 0/0 | 0/0 | 0/0 | 0/1 | 3/1 |
| *P. hermannsburgensis* | 2/2 | 0/0 | 0/1 | 4/2 | 0/0 | 3/40 | 2/6 | 7/14 | 1/15 | 19/80 |
| *Z. argurus* | 0/10 | 0/0 | 0/7 | 0/0 | 0/1 | 0/9 | 0/19 | 0/10 | 0/11 | 0/67 |
| Total terrestrial mammals | 25 | 5 | 39 | 18 | 8 | 157 | 63 | 44 | 49 | 408 |
| Trap nights | 324/1560 | 282/0 | 312/1240 | 318/1240 | 24/448 | 240/1017 | 432/1167 | 216/782 | 336/1017 | 2484/8131 |

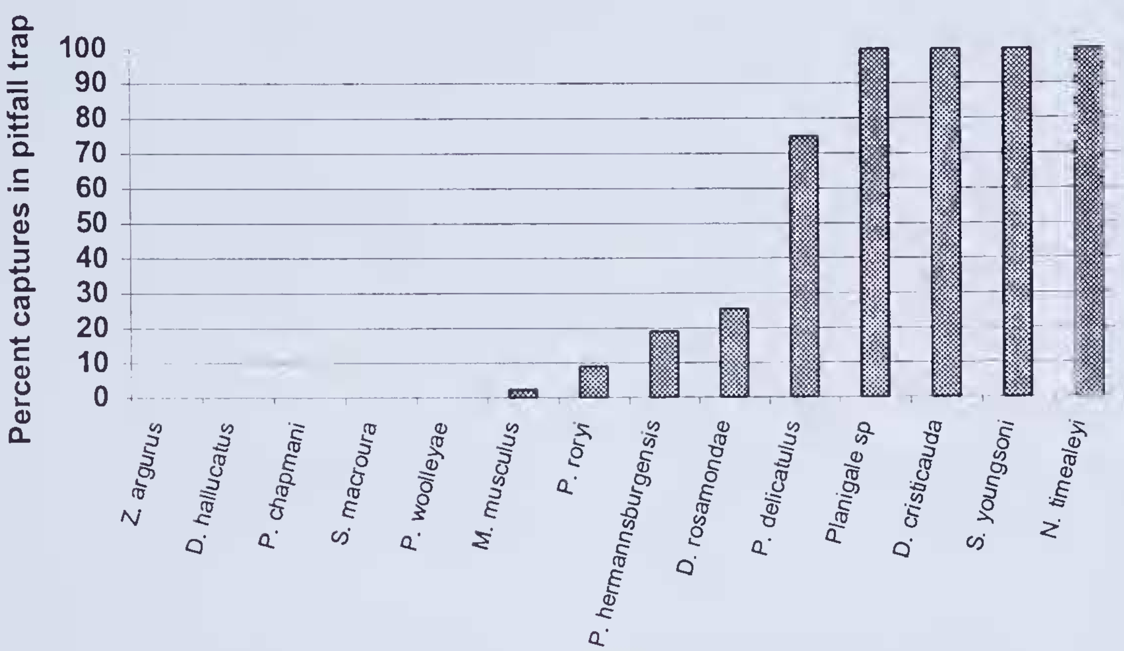


**Figure 3.** Percentage of captures of each species made in pitfall traps.

*Planigale* sp and *D. cristicauda*) were represented by a single individual in the regional assemblage. The capture rate of all small mammal species over all species, sites and sampling periods averaged only 3.84 per hundred trapnights (Table 2). The 8131 Elliott trapnights resulted in the capture of 330 individuals of 10 small mammal species and the 2484 pitfall trapnights in the capture of 78 individuals of 9 species.

Five species recorded during most sampling periods (*D. rosamondae, N. timealeyi, M. musculus, P. hermannsburgensis, Z. argurus*) provided information on temporal variation in body mass, population capture rates and reproductive status. These five species were examined for sexual dimorphism in body size, determined by head-vent length, and body mass. Only *N. timealeyi* showed sexual dimorphism, with males significantly larger ($P = 0.0045$) and heavier ($P = 0.0003$) than females. The mean body mass for adult females of each species during the study is presented in Table 3. No significant changes occurred in body mass of adult female *D. rosamondae* or *N. timealeyi* throughout the survey. For *Z. argurus*, highest female mass occurred in March 1988 compared to September 1988, 1989 and October 1990. Female *P. hermannsburgensis* had higher body mass in March 1990 than July 1990, September 1989 and October 1990. The highest body mass of *M. musculus* females occurred during February (Table 3).

Capture rates of these five species were generally less than one individual per 100 trapnights throughout the survey. Capture rates during both May 1988 and April

Table 3

Body weight (grams) of adult females of the five common small mammals of the Abydos Plain. Data for each sampling period are presented as mean ± standard deviation with sample size in parentheses.

| | *D. rosamondae* | *N. timealeyi* | *M. musculus* | *P. hermannsburgensis* | *Z. argurus* |
|---|---|---|---|---|---|
| March 1988 | - | 4.8±2.0(2) | 10.5(1) | 12.0±1.4(2) | 45.0±3.6(6) |
| May1988 | - | 4.5±1.0(3) | - | - | - |
| September 1988 | 27.0(1) | | 11.7±3.8(7) | - | 32.9±8.4(4) |
| February 1989 | - | 3.3±0.3(3) | 18.5±2. 8(3) | 12.6(1) | - |
| April 1989 | - | | - | - | - |
| September 1989 | 28.5±0.7(2) | 5.1±0.1(2) | 9.6±2.6(31) | 9.9±2.2(19) | 34.4±11.0(6) |
| March 1990 | 29.0±4.2(2) | 4.4±1.9(3) | 12.0±0.9(3) | 13.5±3.2(3) | 36.3±9.4(8) |
| July 1990 | - | 3.5(1) | - | 9.4±2.8(11) | 35.7±1.2(3) |
| October 1990 | 22. 5±2.9(8) | 6.0(1) | 9.0±2.2(3) | 10.0±0.7(5) | 34.7±6.6(7) |
| Significant Differences (P<0.05) | | | Feb89>Oct90, Sep89, Mar88, Mar90, Sep88, Jul90 | Mar90>Oct90, Sep88, Jul90 | Mar88>Oct90, Sep89, Sep88 |

Table 4

Capture rates of the five common small mammal species of the Abydos Plain during major sampling periods presented as number of captures per 100 trapnights. The percentage change from March 1988 (taken as 100%) is given in parentheses. Only periods when both trap types were employed are evaluated for determining variation = peak/trough capture rates.

| | Mar-88 | Sep-88 | Feb-89 | Sep-89 | Mar-90 | Jul-90 | Oct-90 | Variation |
|---|---|---|---|---|---|---|---|---|
| Trapnights | 1884 | 1552 | 1218 | 1257 | 1599 | 998 | 1353 | |
| *D. rosamondae* | 0.16(100) | 0.58(364) | 0.08(52) | 0.64(399) | 1.19(746) | 0.20(126) | 0.67(418) | 14.9x |
| *M. musculus* | 0.16(100) | 0.97(607) | 0.49(309) | 6.21(3897) | 0.50(314) | 0.20(125) | 0.30(186) | 38.8x |
| *N. timealeyi* | 0.21(100) | 0.26(121) | 0.33(154) | 0.95(450) | 0.19(88) | 0.10(47) | 0.22(104) | 9.5x |
| *P. hermannsburgensis* | 0.21(100) | 0.06(30) | 0.49(232) | 3.42(1611) | 0.50(235) | 2.10(991) | 1.18(557) | 57.0x |
| *Z. argurus* | 0.53(100) | 0.45(85) | 0 | 0.72(135) | 1.19(224) | 1.00(189) | 0.81(153) | 2.6x |

1989 are not regarded as representative of population trends as both trap types were not used during these sampling periods. The change in capture rates of the five species between sampling periods is summarised in Table 4 and the percentage change between March 1988 and each subsequent sampling period is also documented. The first sampling period of March 1988 coincided with the end of a three-year dry spell and numbers of all species were expected to be at a minimum. *D. rosamondae* capture rate was highest in March 1990, when a relatively large number of juvenile individuals was caught, and lowest in February 1989. The highest capture rate of *N. timealeyi* occurred in September 1989 and the lowest in July of 1990. The capture rates of these two species of dasyurid and the rock rat (*Z. argurus*) showed relatively small variation throughout the survey, with peaks and troughs varying between 2.6 and 14.9 times (Table 4). Peak activity of *M. musculus* and *P. hermannsburgensis* occurred in September 1989, when capture rates were 39 times and 57 times greater than during troughs in March 1988 and September 1988, respectively. *Mus musculus* also showed an increase of 600 percent in capture rate between March 1988 and September 1988 while capture rates of *P. hermannsburgensis* declined to 30 percent over the same period (Table 4). Spearman rank correlation showed no significant concordance of pattern for any of the five species between seasonally ranked capture rates and adult body mass, indicating that no species attained maximum capture rates at the time of best body condition.

A female *D. rosamondae* collected in September 1989 was in oestrus. Three juveniles were captured in March 1988, one in February 1989 and sixteen (8 females, 8 males) in March 1990. These juveniles had an average body weight of 18.9 ± 2.7g compared with 29g for two adult females captured in the same season. No adult males were trapped in February or March of any year. Female *N. timealeyi* with 5 pouch young were trapped in March 1988 and March 1990. The average crown-

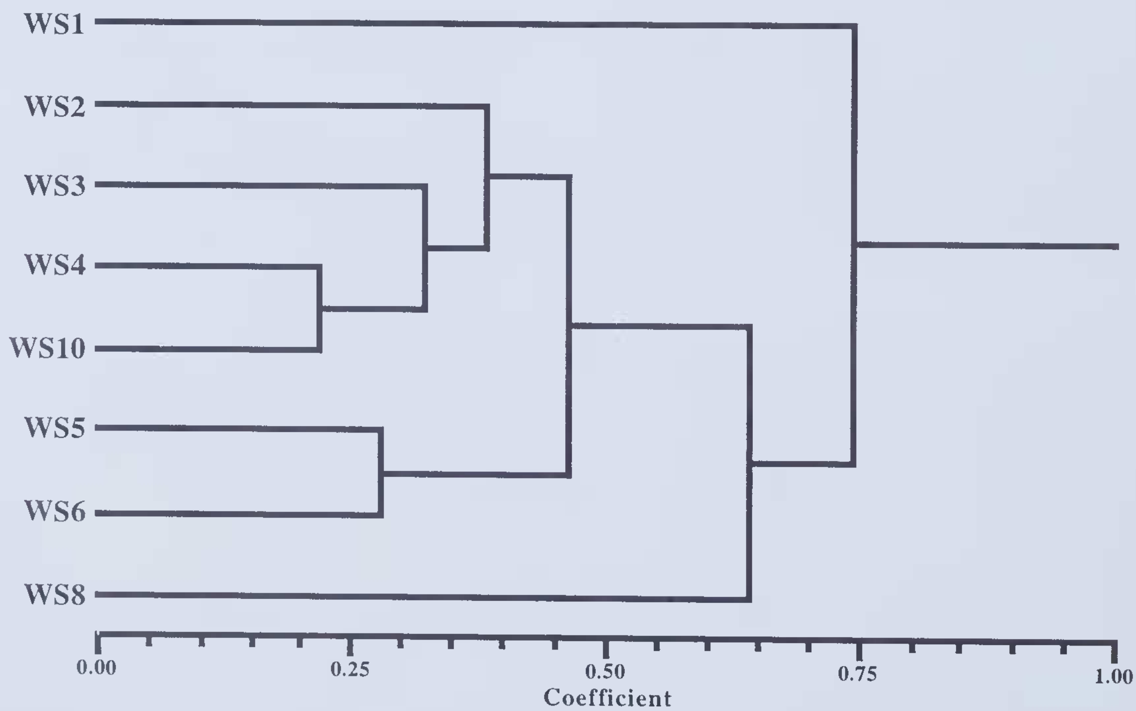


Figure 4. Dendrogram of similarity between the eight major habitats surveyed based on their small mammal assemblages. Bray-Curtis similarity indices were clustered using UPGMA.

Table 5

The number of captures of each small mammal species on each of the intensively trapped sampling sites on the Abydos Plain.

| SITES | WS1 | WS2 | WS3 | WS4 | WS10 | WS5 | WS6 | WS8 |
|---|---|---|---|---|---|---|---|---|
| *D. cristicauda* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *D. hallucatus* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| *D. rosamondae* | 0 | 2 | 4 | 8 | 4 | 10 | 11 | 1 |
| *M. musculus* | 37 | 24 | 10 | 10 | 10 | 5 | 0 | 4 |
| *N. timealeyi* | 0 | 3 | 7 | 4 | 6 | 0 | 4 | 12 |
| *P. chapmani* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *P. delicatulus* | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| *P. hermannsburgensis* | 0 | 10 | 3 | 13 | 21 | 8 | 11 | 2 |
| *P. roryi* | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 |
| *P. woolleyae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Planigale* sp | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *S. macroura* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| *S. youngsoni* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Z. argurus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |

rump length for each litter was 8.6 mm. Adults were caught in each trip (except July 1989 when no pit-traps were open) and juveniles were caught on all trips except July 1990 and September 1988. Pregnant *P. hermannsburgensis* were trapped in February 1989, September 1989 and March 1990, but parous females were trapped on all other trips except for October 1990 when adult females were neither pregnant nor parous. Female *Z. argurus* were pregnant on each spring and summer sampling. Pregnant *M. musculus* were caught on almost all trips between February 1989 and March 1990 and over 30 juveniles were captured in September 1989.

### Habitat relationships

Several taxa were confined, or predominantly restricted to, specific habitats when all sampling techniques and habitats were considered. All *P. chapmani* were caught in Elliott traps on pebble mounds on the scree slopes of the George Fold Range adjacent to the Abydos Plain, while the majority of *D. hallucatus, P. roryi, P. woolleyae* and *Z. argurus* were trapped in Elliott traps on or adjacent to the granite tors and rockpiles. All three *Pseudomys* species were captured in Elliott traps on a single pebble mound on scree slopes.

Comparisons of small mammal assemblages were confined to the eight habitats where both trap types were employed due to the varied capture responses of individual species to differing trap type (Fig 3). The similarity between these eight habitats based on their small mammal assemblages is presented in Fig 4. Three clusters are recognisable at greater than 50% similarity. These conform to three discernibly different habitat groups among the eight compared. Bunchgrass on the deep alluviums adjacent to Coorong Creek (WS1) is markedly different to sites located on the broad sandplain dominated by *Triodia* species and occasional *Acacia* shrubs (WS2, WS3, WS4, WS5, WS6 and WS10) and the loams adjacent to the only calcrete breakaway sampled (WS8). Only two species (Table 5) were recorded at WS1, *M. musculus* and *P. delicatulus*. Three species were trapped only at WS8 (*P. woolleyae, Planigale* sp, *Z. argurus*). *Mus musculus* was numerically dominant (Table 5) at WS1 and WS2 with all captures at other sites occurring on or after the major population eruption of September 1989.

The small mammal species and individuals caught in three *Triodia*-dominated sandplain sites before and after the burn in January 1990 (WS2, WS3, WS4) and those caught in three other *Triodia*-dominated sites that remained unburnt throughout the study (WS5, WS6, WS10) are summarised in Table 6. Fewer species and individuals were trapped in burnt sites after the fire, while in the 'control' sites more species and individuals were trapped in the three sampling periods after the January 1990 fires than in the six sampling periods before it. Three species were caught in Elliott traps in recently burnt areas (Table 6); all in traps placed in unburnt *Triodia* patches within 50 metres of the burnt fenced pitfall traplines. No individuals were pitfall trapped in recently burnt areas and there was no evidence of mass migration into unburnt habitats after fire.

Table 6

Mammal species and individuals caught on three Abydos Plain sampling sites (WS2, WS3, WS5) before and after they were burnt in January 1990, and three 'control' sites (WS5, WS6, WS10) that remained unburnt throughout the study.

| | Burnt Sites | | Unburnt Sites | |
|---|---|---|---|---|
| | Pre1990 | Post1990 | Pre1990 | Post1990 |
| Trapnights | 2019 | 940 | 1723 | 996 |
| *D. hallucatus* | 1 | 0 | - | - |
| *D. cristicauda* | - | - | 0 | 1 |
| *D. rosamondae* | 14 | 0 | 6 | 19 |
| *N. timealeyi* | 14 | 0 | 8 | 2 |
| *P. roryi* | 0 | 2 | 0 | 1 |
| *S. macroura* | - | - | 1 | 0 |
| *S. youngsoni* | - | - | 0 | 1 |
| *M. musculus* | 41 | 3 | 13 | 2 |
| *P. delicatulus* | 1 | 0 | - | - |
| *P. hermannsburgensis* | 9 | 17 | 25 | 15 |
| Total Species | 6 | 3 | 5 | 7 |
| Total Individuals | 80 | 22 | 53 | 41 |
| Individuals per 100 trap nights | 3.96 | 2.34 | 3.08 | 4.12 |

## Discussion

Fourteen species of terrestrial small mammal have been recorded from the Abydos Plain. This represents a diverse community when compared with other locations in central Australia (Masters 1993), the southern Pilbara (Dunlop & Sawle 1980; Anstee, Hamersley Iron, personal communication) and the eastern Pilbara (P Kendrick, CALM, personal communication). Included in this diverse assemblage are four species (*D. rosamondae, N. timealeyi, P. roryi, P. chapmani)* endemic to the Pilbara and regions immediately adjacent, while the distribution of *Z. argurus* in arid Australia is confined to the Pilbara and adjacent offshore islands (Fleming 1996). Despite over 50 years of scientific investigation of the Woodstock and Abydos Stations, four small mammal species were recorded for the first time during the study and it is probable that additional species will be recorded (Fig 2) with greater sampling effort. An examination of the distribution of mammal specimens in the Western Australian Museum collection indicated that other rodents (*e.g. Notomys alexis, Pseudomys desertor, Leggadina lakedownensis)* and a dasyurid marsupial *(Sminthopsis longicaudata*) could occur on the Abydos Plain.

Two of the five species captured regularly through the study, *D. rosamondae* and *N. timealeyi*, are endemic to the Pilbara region and there have been no previous studies of their natural populations. A recent synthesis of information on a third Pilbara endemic, *P. chapmani*, has led to that species being removed from Western Australia's Threatened Fauna list (Start *et al.* 2000).

### Reproduction

Both of the commonly captured dasyurid marsupials had broadly seasonal patterns of reproduction. *Dasykaluta rosamondae* has a male die-off in October, and up to eight young are weaned in February and March (Woolley 1991b). It is the only dasyurid in arid Australia that has a synchronised annual male die-off. This was confirmed during this study when a male, in 'poor condition' and losing fur, was caught by hand during the day in late October 1990, and by the absence of adult males but the presence of numerous juveniles in the population during February and March sampling periods. The observed reproductive status of *N. timealeyi* on the Abydos Plain complements earlier studies (Dunlop & Sawle 1982; Kitchener *et al.* 1986) that determined females had six teats and a breeding peak between September and March; adult males were present in the population throughout the year. Dickman *et al.* (2001) showed breeding occurring in late winter and spring in field populations of the dasyurids *S. youngsoni* and *D. cristicauda* in the Simpson Desert.

The three frequently trapped rodent species on the Abydos Plain had markedly different reproductive patterns and potential. Both *Z. argurus* and *P. hermannsburgensis* have four teats (two inguinal pairs) while *M. musculus* has 12 teats (three inguinal and three pectoral pairs) (Watts & Aslin 1981) and thus a greater reproductive potential. *Zyzomys argurus* showed evidence of reproductive activity in most sampling periods and juvenile and sub-adult animals were present throughout the study. This contrasts with populations of this species in Arnhem Land (Begg 1981) and the north Kimberley (Bradley *et al.* 1988) where peak reproductive activity occurred at the end of the wet season (April) with populations in the north Kimberley also showing major temporal and spatial changes in abundance (Bradley *et al.* 1988). *Pseudomys hermannsburgensis* has the potential to breed at any time of the year (Breed 1982, 1990) and reproductive activity was apparent in most sampling periods on the Abydos Plain. The reproductive potential of *M. musculus* has been well documented in Australia over many years and in numerous areas (Newsome 1969; Chapman 1981; Singleton & Redhead 1991; Masters 1993). The presence of adult female *M. musculus* in reproductive condition during all sampling periods on the Abydos Plain illustrates the species' latent reproductive ability and its capacity to respond quickly to improved environmental conditions.

### Population fluctuations

The commonly captured rodents and dasyurid marsupials on the Abydos Plain also showed different fluctuations in numbers caught over the three-year study. Neither of the dasyurid species showed large population fluctuations despite two consecutive summers with above average rainfall (Table 4). Variation in capture rates for both dasyurids are more readily explained by the introduction of juveniles into the population after seasonal reproductive events. Masters (1993) also found only slight increases in dasyurid populations over three-years at Uluru and showed they contrasted with rodents in their demographic correlates with environmental variables; only one dasyurid had 'cumulative deviation from mean rainfall' as a significant positive correlate with numbers, while the populations of the four rodent species showed significant correlation with previous rainfall (Masters 1993). Dickman *et al.* (2001) described capture rates of all dasyurid species in the Simpson desert as low, 'as in many other studies of arid zone dasyurids', and showed that capture rates were associated with different environmental variables in each of the three species they studied.

Capture rates of *M. musculus* and *P. hermannsburgensis* were 40-50 times higher in the peaks than the troughs on the Abydos Plain. However, *Z. argurus*, like the two dasyurids, had small changes in capture rates throughout the study. Decreased abundance of *Z. argurus* populations occurred during April in both Arnhem Land (Begg 1981) and the north Kimberley (Bradley *et al.* 1988). No captures of this species were made in the study area during February 1989, while in April 1989 a single juvenile was captured. The highest capture rates of *M. musculus* and *P. hermannsburgensis* occurred in September 1989, some 18 months after major rainfall in March 1988 and seven months after the equally heavy summer rains of February 1989. There was no population eruption in *P. hermannsburgensis* within the first 12 months after the major post-cyclonic rains of March 1988; however, by September 1989 capture rates were over 50 times that of the preceding September (Table 4). Capture rates increased six times in *M. musculus* from March 1988 to September 1988 and to nearly 39 times by the following September. The contrast in species responses to the first post–cyclonic rainfall in March 1988 can be seen by the fact that *P. hermannsburgensis* capture rates declined to 30 percent by September 1988 while *M. musculus* had increased by 600 percent over the same period (Table 4).

Dickman *et al.* (1999) collated information on long-term population changes for four rodents (*M. musculus, N. alexis, P. hermannsburgensis, P. desertor)* in arid Australia and showed that they erupted after significant rainfall periods but remained in low numbers or were absent during droughts. Population peaks occurred two months after rain for *M. musculus*, but between three and 10 months after rain for *N. alexis, P. hermannsburgensis* and *P. desertor*. Numerical changes between population peaks and troughs for all rodent species were several orders of magnitude and all species disappeared from the trap record on some occasion (Dickman *et al.* 1999). Dickman *et al.* (1999) also modelled the relationship between the cumulative mean rainfall residual (CMRR) and small mammal abundance to show that, for most species, there was a strong positive correlation between rodent population peaks and the impact of earlier rainfall events. However, not all populations in all areas followed their predictive model. *P. hermannsburgensis* populations erupted at Uluru in 1993-94 in the absence of significant rainfall while *P. hermannsburgensis, N. alexis* and *P. desertor* populations failed to respond to the significant summer rains of 1986-87 in the Tanami Desert area. They suggested that variation in numerical responses both within and between species may result from differing reproductive potential of the species, lower starting densities (possibly maintained by predation) or differences in resource states for species between study areas. Predavec (1994) also indicated that population structure in desert rodents fluctuated by 40 times between the peaks and troughs with a lag of four months between a rainfall event and peak density. *Mus musculus* populations at Uluru required prolonged exposure to wet conditions after an extended drought before showing major population peaks (Masters 1993). Similar responses in activity of *M. musculus* were encountered during this study.

On the Abydos Plain, the drought-breaking rains of March 1988 did not precede peak capture rates in any of the five common species either two months (May 1988) or six months (September 1988) later, although lag times of two to six months led to significant increases in rodent populations in central and eastern arid areas of Australia (Predavec 1994; Dickman *et al.* 1999). A second, major summer rainfall event on the Abydos Plain in February 1989 had little impact on rodent populations by April 1989. However, by September 1989 capture rates of both *M. musculus* and *P. hermannsburgensis* had peaked at around 7–12 times the levels noted in February of 1989, and between 40 and 50 times those of population troughs some 12 to 18 months previously. Changes in capture rates of the saxicoline rodent *Z. argurus* and the dasyurids *D. rosamondae* and *N. timealeyi* were far less than these over the three years of sampling. The former occurs in the less variable environments associated with granite tors and rock outcrops, while the latter marsupials have differing yet seasonal reproductive patterns (Lee *et al.* 1982) that are not conducive to eruptive population responses to improved environmental conditions.

Differences between arid zone dasyurids and rodents also extend to diet. A study of 16 species of arid rodents (including several species examined in this study) concluded that the dietary pattern was 'overwhelmingly' omnivorous (Murray *et al.* 1999) while the diets of six arid zone dasyurid species (Fisher & Dickman 1993) were almost exclusively insectivorous. The most obvious initial environmental response to major rainfall in arid areas is the flush of new vegetative growth, generally followed by seeding in grasses and an increase in invertebrate activity. Our studies on the Abydos Plain included an examination of invertebrate diversity (Harvey & Waldock 1991) that increased in the first six months following rain (M Harvey, WA Museum, personal communication), a pattern of increase similar to that documented by Fisher & Dickman (1993). Increased invertebrate activity increases prey availability for insectivorous marsupials; however, being seasonal breeders with fixed litter sizes (based on the number of teats), their demographic response will be restricted to either improved survival of pouch young or recently independent juveniles.

### Body mass

Our examination of body mass changes of the five frequently trapped small mammals showed no significant changes occurred for adult female *N. timealeyi* or *D. rosamondae* during the study, even though invertebrate abundance increased after major rainfall at the start of the study. For *Z. argurus*, maximum female body mass was recorded in the populations during March 1988, the period during which major post-cyclonic rainfall broke a three-year long dry spell (Tinley 1991a). *Pseudomys hermannsburgensis* females were heaviest during March 1990 when body mass was significantly higher than during either the population peak of September 1989 or the declining populations of July and October 1990. The peak body mass of female *M. musculus* occurred during February 1989, immediately after the second above average summer rainfall and prior to the population peak of September 1989.

### Habitat associations

In both arid and semiarid regions of Western Australia's eastern Goldfields, rodents were preferentially trapped in box traps while dasyurid marsupials were more frequently caught in fenced pitfall traps (How *et al.* 1984). Our study has shown major differences between species in their response to capture in different trap types for the Pilbara area (Fig 3). Consequently, only habitats where both trap types were employed were used to interpret assemblage structure (Table 5) and species habitat associations (Fig 4).

Three major habitat groupings were recognised for the terrestrial small mammal species. The deep alluvial soils and tussock grasses adjacent to Coorong Creek contained only *M. musculus* and a single *P. delicatulus*, while the most diverse assemblage was recorded on calcareous clay loams covered by *Triodia* adjacent to a calcrete breakaway. The third group of habitats included all six sampling sites that were dominated by *Triodia* and *Acacia pyrifolia* (Table 5). Although *M. musculus* were present throughout the study area, they were most abundant in the tussock grass banks associated with Coorong Creek; captures away from this habitat occurred when populations were at a peak and individuals appear to have expanded into the surrounding *Triodia* habitats. In central Australia, *M. musculus* is a poor coloniser of

*Triodia*-dominated habitats and only survives in those habitats in wet years (Masters 1993).

The largest variety of habitats sampled during the study were in or adjacent to rocky slopes of the George Fold Ranges and the abundant granite tors on the Abydos Plain; these habitats were sampled using only Elliott traps. The Western Pebble Mound Mouse, *P. chapmani*, was restricted to the rocky slopes associated with the George Fold Ranges, while the majority of captures of *D. hallucatus*, *P. roryi*, *P. woolleyae* and *Z. argurus* were made in and around the granite tors. The granite tors of the Abydos Plain were focal habitat for many faunal species (How *et al.* 1991) including several small mammals, two species of macropod, four bats and numerous snakes and lizards. The capture of three *Pseudomys* species in sympatry on a pebble mound on the scree slopes illustrates that both *P. hermannsburgensis* and *P. delicatulus* will move onto rocky substrates.

Numbers of most small mammals were generally lowest on the Abydos Plain at the commencement of the study in March 1988, a sampling period that occurred at the end of a three year long dry spell and during heavy rain associated with a post-cyclonic depression. We did not detect changes over the study in predator populations although numerous predatory species were present including introduced (fox and cat) and native (*D. cristicauda*, *D. hallucatus*) mammals, various raptors, monitors and snakes (How *et al.* 1991). Competition between granivorous species that use the abundant seed-set of *Triodia* and *Acacia* following major rainfall has not been evaluated as a mechanism influencing rodent population responses to increased food availability. The granivorous bird guild on the Abydos Plain showed a change in flock size and dispersion over the study (How *et al.* 1991) that differed between species but, overall, reflected a change to more aggregated and larger flock sizes with increasing time since major rainfall events. Rabbits, a key agent in competing with native species and altering environments in arid Australia (Morton 1990), were absent from the study site. They have been infrequently recorded in the north-eastern Pilbara where shallow soils are unsuitable for burrow systems and *Triodia* spp are unsuitable for forage (King 1990).

### Fire response

The response of rodents to fire in arid Australia has been well documented (Friend 1993; Masters 1993; Southgate & Masters 1996; Sutherland & Dickman 1999). Our data show that, in *Triodia* dominated habitats where similar assemblages occur, fewer species and fewer individuals were trapped in habitats following fire than in habitats that remained unburnt throughout the study (Table 6). However, there was no indication that the widespread but small-scale burns of February 1990 had any discernable impact on total mammal populations, several of which were declining following peaks in capture rates across the Abydos Plain.

Fires were not considered to have had a significant impact on the eruptive response of rodent populations at either Uluru or Tanami study sites by Dickman *et al.* (1999) as they preceded the onset of the eruptive cycle. Additionally, it has been shown that many mammal species exhibit large-scale movements in *Triodia* communities of the arid zone (Dickman *et al.* 1995, 2001) that would enable them to avoid or move quickly through small-scale burn patches. Fire has been suggested as a major management technique for maintaining the diversity of small mammal assemblages across a mosaic of successional communities at Uluru (Masters 1993). The fires on the Abydos Plain could similarly assist in maintaining the small mammal diversity by leaving refugia for species and developing an array of successional habitats across the landscape.

The diverse assemblage of terrestrial small mammals sampled during this three year study in the arid north-eastern Pilbara showed well defined habitat preferences in most species, differing species responses to trap types and highly variable responses to changing environmental conditions following major rainfall events. Two rodents exhibited very high rates of capture about 18 months after the first major post-cyclonic rain, although most of the remaining 12 species had low rates of capture throughout the study. Continued sampling is likely to increase the number of species known from this environmentally heterogeneous area.

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